

# Large Eddy Simulation of Air Flow around the Air-Sea Interaction Tower

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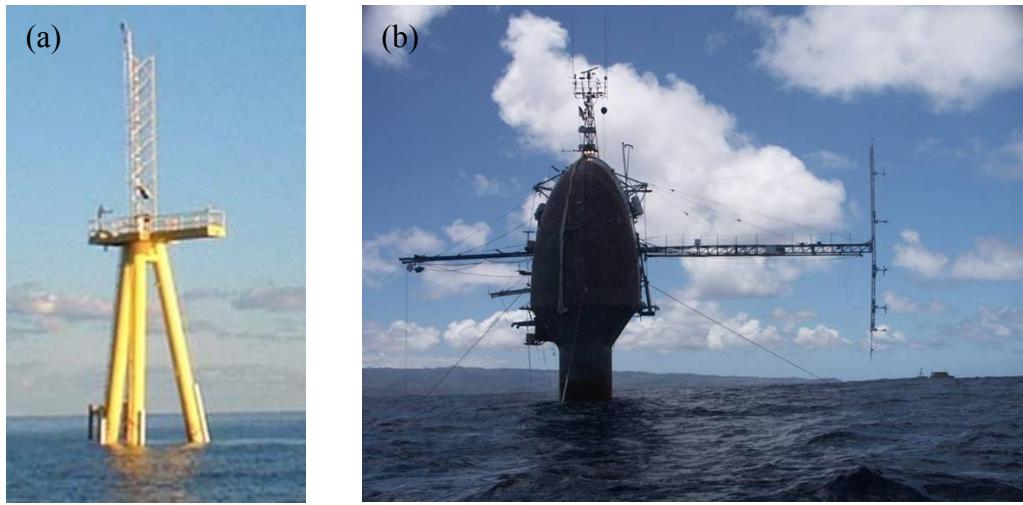
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## LONG-TERM GOALS

The dynamics of the coupled marine boundary layer (MBL) are driven by multiscale and multiphase processes. A thorough understanding of these processes would have a profound impact on Naval worldwide operations. The coupled MBL dynamics are classified into three regimes: low wind (wind speed less than 5m/s), high wind, and hurricane. In order to study the MBL under the low-wind condition as part of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program, the Air-Sea Interaction Tower (ASIT, Fig. 1(a)) has been constructed off the south shore of Martha's Vineyard. The long-term goal of the project is to investigate the flow around the ASIT by large-eddy simulation (LES) technique and to help field experimenters interpret their data measured around the tower. The flow distortion around the Floating Instrument Platform (FLIP), which is a 355-foot (108-meter) spoon-shaped buoy (Fig. 1(b)) will be simulated and studied as well using LES.



*Figure 1: Snapshots of (a) ASIT, (b) FLIP.*

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14. ABSTRACT <p><b>The dynamics of the coupled marine boundary layer (MBL) are driven by multiscale and multiphase processes. A thorough understanding of these processes would have a profound impact on Naval worldwide operations. The coupled MBL dynamics are classified into three regimes: low wind (wind speed less than 5m/s), high wind, and hurricane. In order to study the MBL under the low-wind condition as part of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program, the Air-Sea Interaction Tower (ASIT, Fig. 1(a)) has been constructed off the south shore of Martha's Vineyard. The long-term goal of the project is to investigate the flow around the ASIT by large-eddy simulation (LES) technique and to help field experimenters interpret their data measured around the tower. The flow distortion around the Floating Instrument Platform (FLIP), which is a 355-foot (108-meter) spoon-shaped buoy (Fig. 1(b)) will be simulated and studied as well using LES.</b></p>					
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## OBJECTIVES

The main objective of the proposed research is to investigate the effect of flow distortion caused by the ASIT and FLIP on the measurement data.

## APPROACH

The implicit level-set finite element method (LSFEM) for two phase flows developed by the PI (Lin et al., 2005) has been used for the proposed research. The characteristic Galerkin finite element method is applied to solve incompressible, variable-density Navier-Stokes equations and level-set evolution and reinitialization equations. Because the inherent geometric flexibility of the finite element method permits easy use of simple Cartesian variables on unstructured meshes for arbitrary complex geometries, there is no need for global mapping and transformation of equations to covariant (or contravariant) components. The finite element method also permits to exploit the parallelism in a straightforward manner because the spatial domain is discretized at the element level and inter-elemental communications are required only during the conjugate-gradient type iterative procedure for solving the algebraic systems.

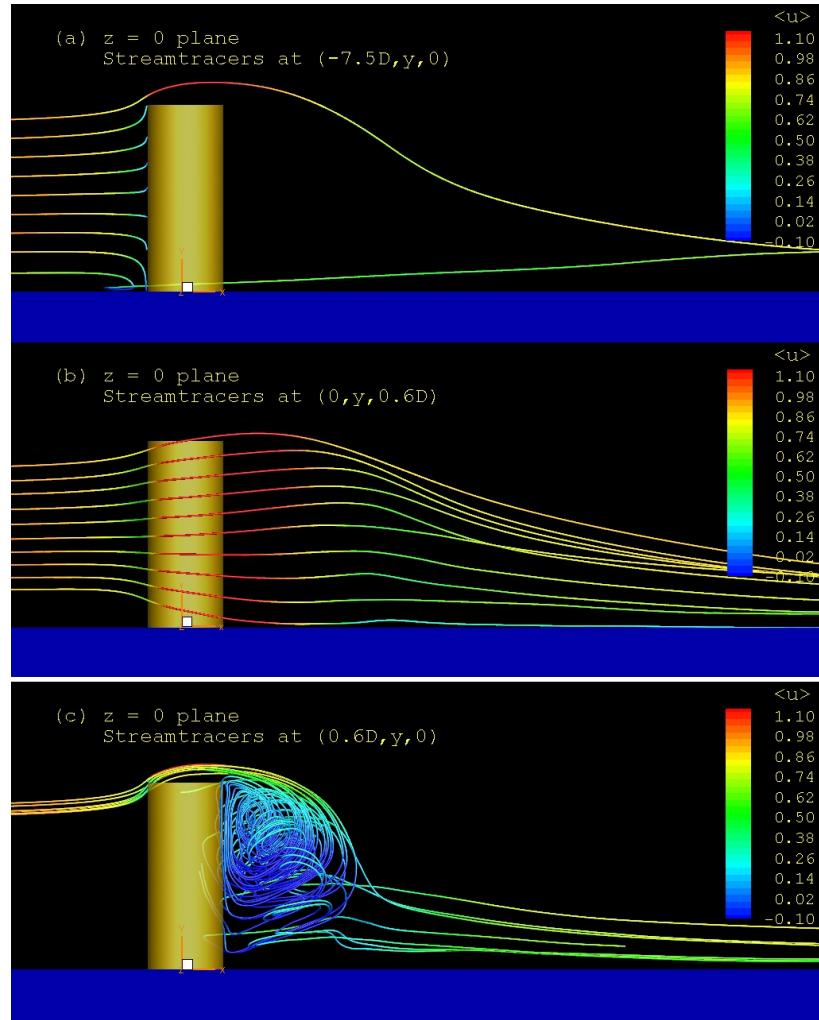
## WORK COMPLETED

The LES of air flow around short and long cylinders, ASIT and FLIP have been simulated using the LSFEM code. The code has also been successfully parallelized for running on linux clusters.

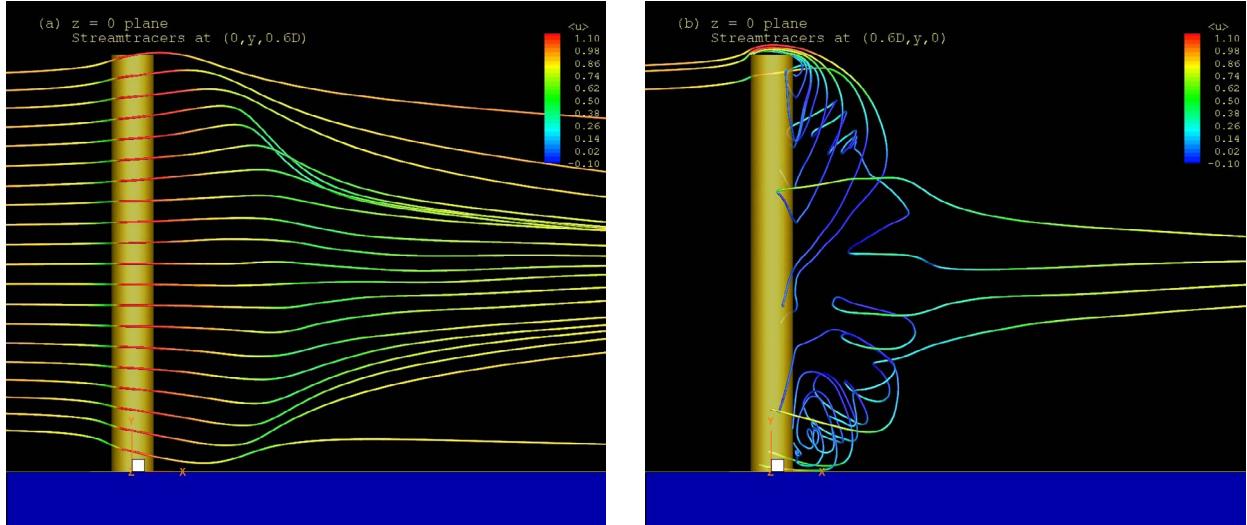
## RESULTS

In order to examine the flow around ASIT, it is necessary to fully understand the flow around a single wall-mounted cylinder. According to Kawamura et al. (1984), when the height-to-diameter ratio  $H/D$  is high enough ( $H/D > 6$ ), the periodic vortex shedding is expected along with the trailing vortex due to the end effect and the necklace vortex at a junction. As  $H/D$  is reduced, the periodic vortex shedding is suppressed in the range of  $H/D < 2$ . The flow around ASIT belongs to the long cylinder case with high  $H/D$  ratio ( $H/D \sim 10$ ). In this research, we present LES of flow around a wall-mounted circular cylinder with varying heights ( $H/D = 2.5, H/D = 10$ ), and then flow around ASIT. The aforementioned LSFEM is used for this purpose. For the case of  $H/D = 2.5$ , the present calculation predicts the mean drag coefficient  $C_D$  of 0.71 which lies in the range between  $C_D$  obtained from the LES Smagorinsky model ( $C_D = 0.88$ ) and the LES dynamic model ( $C_D = 0.60$ ) by Fröhlich and Rodi (2004) who used a grid of almost 20 times denser than the present case. Experimental values available from the literature for the case with  $H/D = 2$  are  $C_D = 0.78$  (Kawamura et al., 1984) and  $C_D = 0.73$  (Okamoto and Sunabashiri, 1992). The good agreement between our calculation and experimental data suggests the present model is very accurate and has the superb advantage of optimal grid flexibility as compared with other existing LES models. For the case with  $H/D = 2.5$ , streamtracer analyses are performed in various planes in the computational domain. In Fig. 2(a), the streamtracers are initially located in  $(-7.5D, y, 0)$  plane (upstream) and most of them cannot pass through the cylinder since they hit the stagnation points. It is interesting to note that the streamtracers located near the bottom wall tend to have downward velocity near the stagnation points toward the junction of the cylinder and the bottom wall. This trend results in the downdraft near the cylinder junction as shown in Fig. 2(b) in which the streamtracers start in  $(0, y, 0.6D)$  plane. In Fig. 2(c) the streamtracers are initialized behind the cylinder at  $(0.6D, y, 0)$  to reveal flow separation.

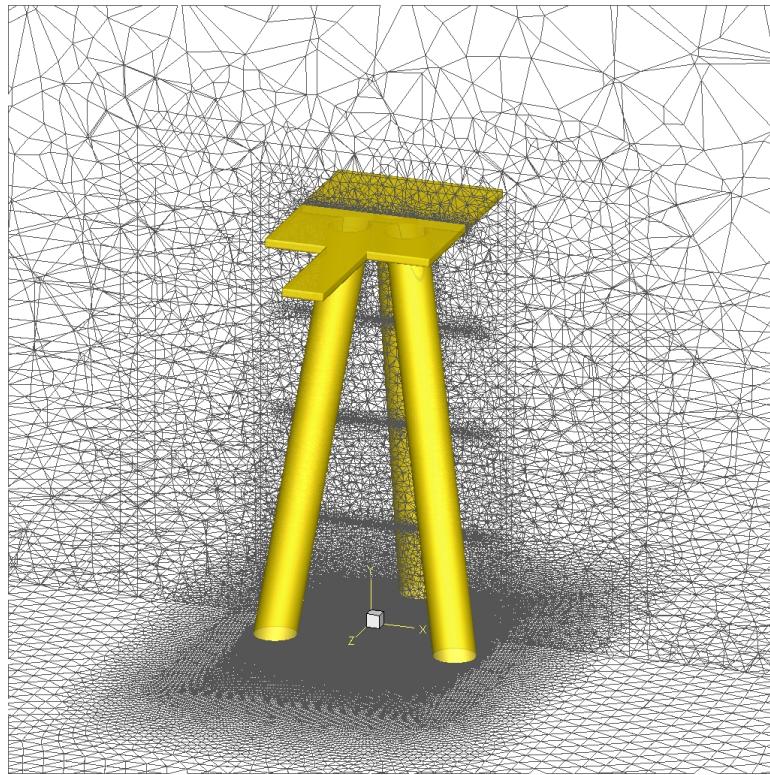
The flow past a circular cylinder of height  $H/D=10$  is also examined in the same computational setup as the case with  $H/D=2.5$ . As shown in Fig. 3(a), the streamtracers merge toward the center of  $z/D=0$  plane, which is not apparent in the case of  $H/D=2.5$ . Averaged vertical structures in Fig. 3(b) reveal that the tip vortices and the necklace vortices are much stronger than the Kármán vortices generated between the tip and the junction. Unlike the short cylinder case, the downward motion of the streamtracers behind the cylinder junction is followed by the strong upward motion at  $x/D \sim 2$  and further downstream. The mesh for the ASIT simulation is displayed in Fig. 4. The flow around the ASIT is much more complicated. The wake regions behind the tower at two different heights are clearly revealed in Fig. 5. In Fig. 6, the streamtracers released in the three different  $z/D$  planes using the averaged velocities are presented. Flow is accelerated inside the ASIT structure and exhibits downdraft near each of the three legs. The effect of the platform on the overall flow structure is minimal because of its slender shape.



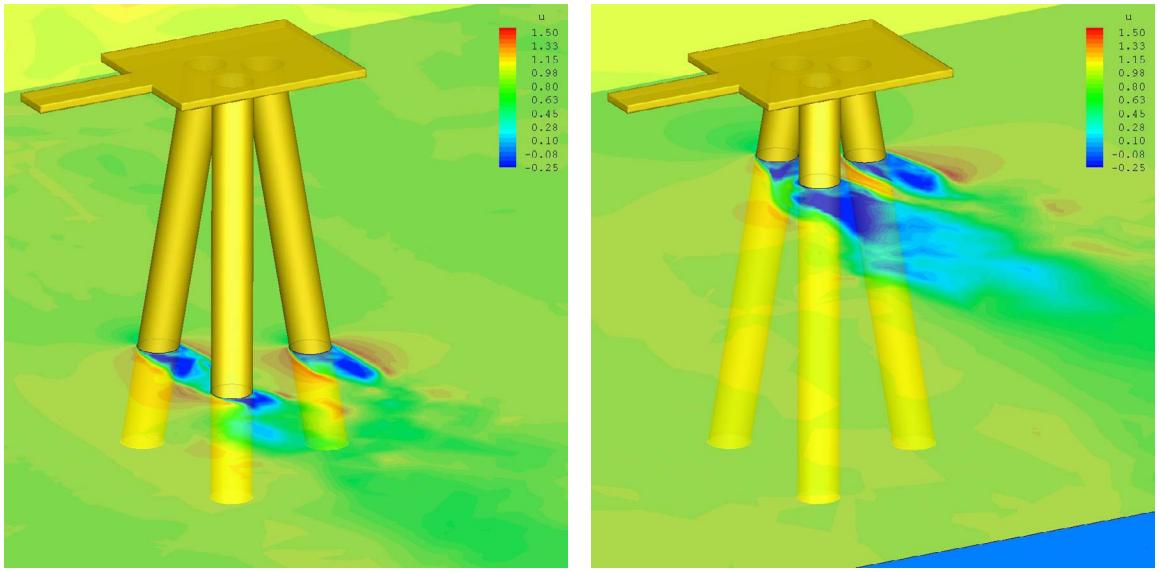
**Figure 2: Mean streamtracers in the  $z = 0$  plane, initially released at (a) the upstream side of the cylinder  $(-7.5D, y, 0)$ ; (b) the lateral side  $(0, y, 0.6D)$ ; (c) behind the cylinder  $(0.6D, y, 0)$ .**



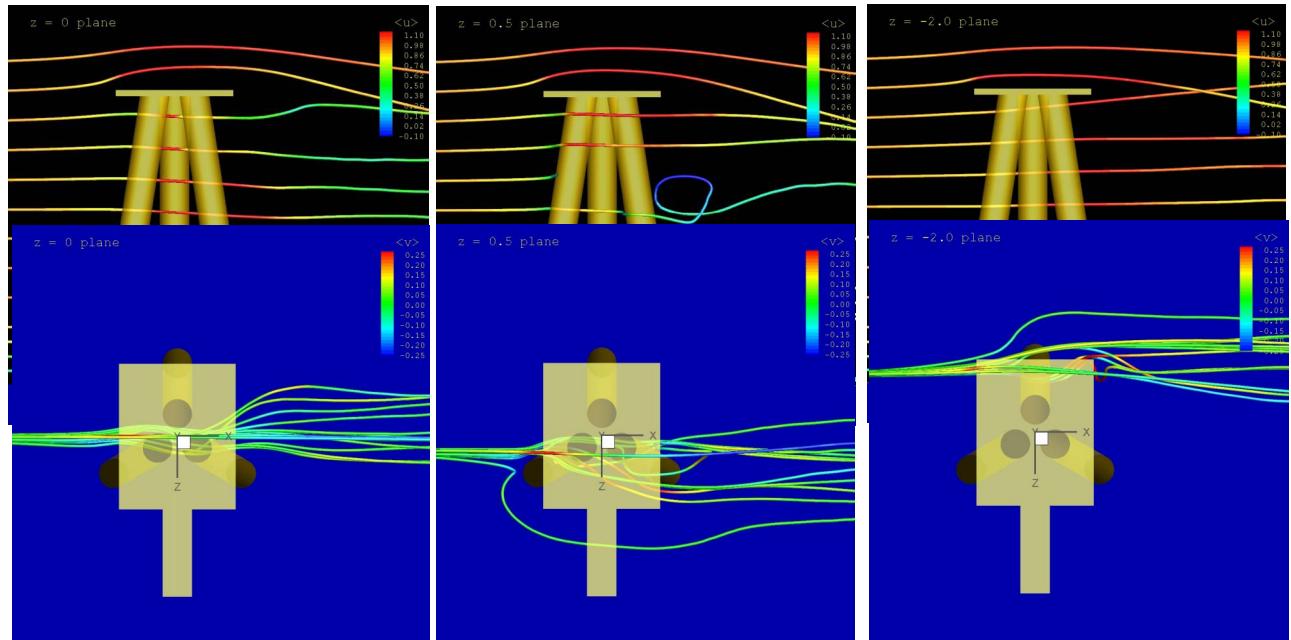
**Figure 3:** Mean streamtracers in the  $z = 0$  plane. Streamtracers initially located at: (a) the lateral side of the cylinder  $(0, y, 0.6D)$ ; (b) behind the cylinder  $(0.6D, y, 0)$ .



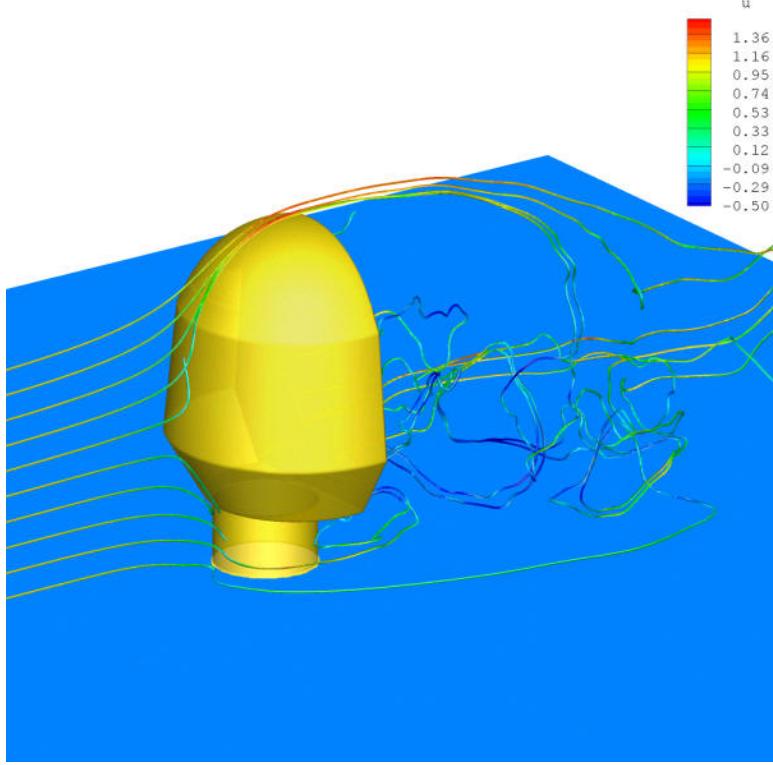
**Figure 4:** A close-up view of tetrahedral unstructured mesh around ASIT. Total number of grid points is 744,517 and total number of elements is 3,806,033. The coordinate axis is located at the geometric center of three cylindrical legs and wind is blowing in the positive x-direction.



*Figure 5: Snapshot of streamwise velocity in (left)  $y = 2.5$  plane, (right)  $y = 7.5$  plane*



*Figure 6: Mean streamtraces (top panel) side view; (lower panel) top view) in  $z =$ : (left) 0 plane, (middle) 0.5 plane, (right) -2.0 plane. Contours on the streamtraces represent mean  $\langle u \rangle$ .*



**Figure 7: LES of air flow around the FLIP**

The LES of the flow around the FLIP has also been performed. The preliminary result is shown in Fig. 7. A large wake region is formed behind the vessel.

## IMPACT/APPLICATIONS

The high-performance LES simulations of air flow around the ASIT and FLIP have been performed. The results reveal the regions of significant flow disturbance, which could assist field experimenters to mount the measurement equipments and sensors at the proper locations of the tower. The results have a potential to assist field experimenters with interpretation of some measurement data. A manuscript entitled “Large Eddy Simulation of the Flow past Wall-Mounted Short and Long Cylinders and the ASIT tower” is under preparation.

## REFERENCES

Fröhlich, J., Rodi, W., 2004. LES of the flow around a circular cylinder of finite height. Int. J. Heat and Fluid Flows 25, 537-548.

Kawamura, T., Hiwada, M., Hibino, T., Mabuchi, I., Kamuda, M., 1984. Flow around a finite circular cylinder on a flat plate. Bull. JSME 27, 2142-2151.

Okamoto, S., Sunabashiri, Y., 1992. Vortex shedding from a circular cylinder of finite length placed on a ground plane. J. Fluids Eng. 114, 512-521.

Lin, C.-L., H. Lee, T. Lee, and L. Weber, ``A Level Set Characteristic Galerkin Finite Element Method for Free Surface Flows'', Int. J. Numer. Meth. in Fluids, Vol. 49, Issue 5, pp. 521-547, 2005.

## PUBLICATIONS

NA (the project starts February 2005)

## HONORS/AWARDS/PRIZES

The postdoctoral research associate Dr. Taehun Lee, who was supported by this ONR award until August 2005 to carry out the above study, has been named the Argonne National Laboratory 2005 Wilkinson Fellow in Scientific Computing, the most prestigious international postdoctoral fellowship in computational mathematics. Dr. Lee is a former PhD student of the PI and will join the department of Mechanical Engineering at the City College of New York as a tenure-track assistant professor.